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ESTIMATING THE EFFICIENCY OF A HILL-TOP WIND-POWER GENERATOR

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Summary

The Memorandum describes how estimates of the efficiency of a hill-top wind-power generator in West Wales were made using i) on-site daily run-of-wind recordings, and ii) wind frequencies recorded at a fairly distant anemograph site with a coastal exposure.

I Introduction

The stated maximum power rating of a wind-generator will be misleading if winds of sufficient strength to generate that power are infrequent. Further, since there is a threshold wind velocity (say 4 ms^{-1}), there may be a high frequency of winds which produce little or no power.

Estimating the efficiency is relatively easy given a nearby representative anemograph station and the power output characteristics of the generator (see for example Ag Mem 824, Taylor 1984 and Appendix A).

At a site reasonably distant from even the nearest anemograph site and amidst quite different topography there is clearly the question of representivity of data: this is the problem posed by the enquiry from a farmer in West Wales.

The enquiry concerned the efficiency of a wind-generator that might be erected on an 18.5 metre mast on top of a 500 m asl hill at Nant-y-Maen 8 km east of Tregaron, Dyfed on the Mid-Wales plateau. Anemograph stations, inland and coastal, are distant from this site; Aberporth, the nearest, is on the Cardigan coast, 40 km to the west, at an altitude of 133m. It is still more appropriate to use as a reference than Cilfynydd, 70 km to SE, or Shawbury (110 km to NE)!

II The Problem

The problem, then, is one of: firstly relating hourly wind speed and direction frequencies at Aberporth to those at Nant-y-maen; secondly, interpreting these frequencies in terms of the power output from a generator at 18.5 m height.

III Wind-speed records at Tregaron and Aberporth 1985

The farmer was requested to make daily morning readings of a cup anemometer, exposed on the hill-top site, at 2 m above short grass. This Memorandum reports on January to April data.

Corresponding daily 10 m wind speeds for Aberporth were extracted from FORM 3208 (available at Ag met departments monthly on a fiché). Average daily wind directions were tabulated using Aberporth hourly anemograph data and, if necessary, daily weather charts.

The graph of daily wind speeds at Tregaron against those at Aberporth as a function of direction (Fig 1) shows clearly the influence of direction; easterlies at Tregaron (at 2 m) are clearly stronger than the 10 m Aberporth winds while westerlies at Tregaron are weaker. A factor of up to 2 or 3 is involved in each case. (Such a wind ratio might be anticipated: westerlies off the sea will be slowed by inland passage although the increase of wind with height will compensate to a degree; the easterlies at 500 m would be expected to be greater than at 133 m, 40 km down-wind over rough terrain.)

FH2B

It is interesting to note that, in the months monitored, the balance of westerlies and easterlies is such that the average daily wind ratio

$\bar{R}$ (= $\frac{\text{Tregaron, 2 m}}{\text{Aberporth 10 m}}$) is virtually unity (Table 1).

Table 1

Month 1985	$\bar{R}$
Jan	1.03
Feb	1.13
March	0.85
April	1.01

However in view of the substantial influence of daily wind directions on the ratio of Tregaron to Aberporth winds the power output of the generator will clearly not be able to be estimated from the average annual distribution of wind speeds at Aberporth.

IV Corrections for height of the wind generator

Following Climat Memo 50A etc the 2 m Tregaron wind over grass (roughness Z_o= 0.02cm) can be adjusted to other heights using the scaling factors:

to 10 m : scaling factor 1.35
to 18.5 m : scaling factor 1.48

V Estimates of wind frequencies at 18.5 m at Tregaron

Daily wind ratios of, $R = \frac{\text{Tregaron (2 m)}}{\text{Aberporth (10 m)}}$ were tabulated (Table 2)

according to wind direction deduced from Aberporth hourly winds using this definition:

Westerlies : 200° to 340°
Easterlies : 020° to 160°
Northerlies/ Southerlies : other directions

Average ratios, $\bar{R}$, for easterly, westerly and northerly/southerly wind components were calculated and then converted to the 18.5 m height values using the scaling factor x 1.48. The factors were 2.35, 1.24 and 1.15 for e, w and n/s winds respectively (Table 2).

Thus a wind of V ms^{-1} at 10 m at Aberporth gives a 18.5 m wind at Tregaron of 2.35 V if an easterly, 1.24 V if a westerly and 1.15 V if a northerly or southerly.

Clearly the power generated at Tregaron by a V ms^{-1} at Aberporth will be a function of direction.

Using Table 2, the % frequency tabulation of wind speed and direction at Aberporth, the % frequencies were found for winds in various speed bands with easterly, westerly and northerly/southerly components (Table 4).

The scaling factors of 2.35, 1.24 and 1.15 were then applied to the speed bands to give equivalent wind speeds at 18.5 m at Tregaron.

Table 4 is presented graphically in Fig 2.

For a given direction the graphs give the % of time winds of less than a stated magnitude blow from a given direction. The % of time the wind blows within a given speed band may be easily deduced.

The relative frequencies for each direction may thus be summed for a given speed band to give the overall frequency of say V to V +ΔV winds at 18.5 m at Nant-y-maen (Table 5).

VI Interpretation of data in terms of power output

Table 5 can be used in conjunction with the power output characteristics of a generator (Fig 3) to estimate the percentage of time that the power output P lies below a stated value. Data for two commercial generators are given in Table 6.

The Vestas 30 (maximum output 30 kw; threshold speed 4 ms^{-1}) produces no power for some 16% of the time, less than 7 kw for 46% of the time and less than 21 kw for 75% of the time. The generator should perform at maximum rating for wind speeds in excess of 14 ms^{-1} ie for some 17% of the time.

The NES generator (maximum output 10 kw, threshold speed 2 ms^{-1}) produces no power for 4½% of the time, less than 2 kw for 27% of the time and less than 9 kw for 62½% of the time. This generator should perform at maximum rating for some 30% of the time.

Acknowledgements

The study was carried out in collaboration with the ADAS Trawsgoed, Mechanisation Department and the contribution of Mr P Hull of that Department is acknowledged. Mr E D Jones of Nant-y-maen, Tregaron took daily anemometer readings at his hill site.

References

Agricultural Memorandum 824 (1977): Wind and Windmills: L D J Harvey

Taylor R H (1984): Wind Power Technology, Phys-Bull 35: 377-380.

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ADAS/WOAD Trawsgoed
Aberystwyth
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Appendix A

Fig A illustrates the wind/power characteristics of three commercial generators superimposed on the cumulative wind-frequency ogive for Aberporth. Assuming Aberporth to be representative of the site of the generators the following information on power generation can be deduced (Table A).

Table A Power characteristics of the 'Vestas 30' generator based on Aberporth wind-frequency data.

Power output (kw) P	Percentage of time that output is less than P (or for P = 0; equal to)
0	38
2	50
5	64
10	80
15	89
20	94
30	98

The generator would thus only deliver the rated maximum power output of 30 kw for 2% of the time. No power would be generated for 38% of the time. This may be contrasted with the percentage times estimated for the Nant-y-maen site (Section VI).

FIG A

ANNUAL CUMULATIVE AVERAGE WIND SPEED AND ASSOCIATED WINDMILL POWER OUTPUT

ABERPORTH (133 M. asl)

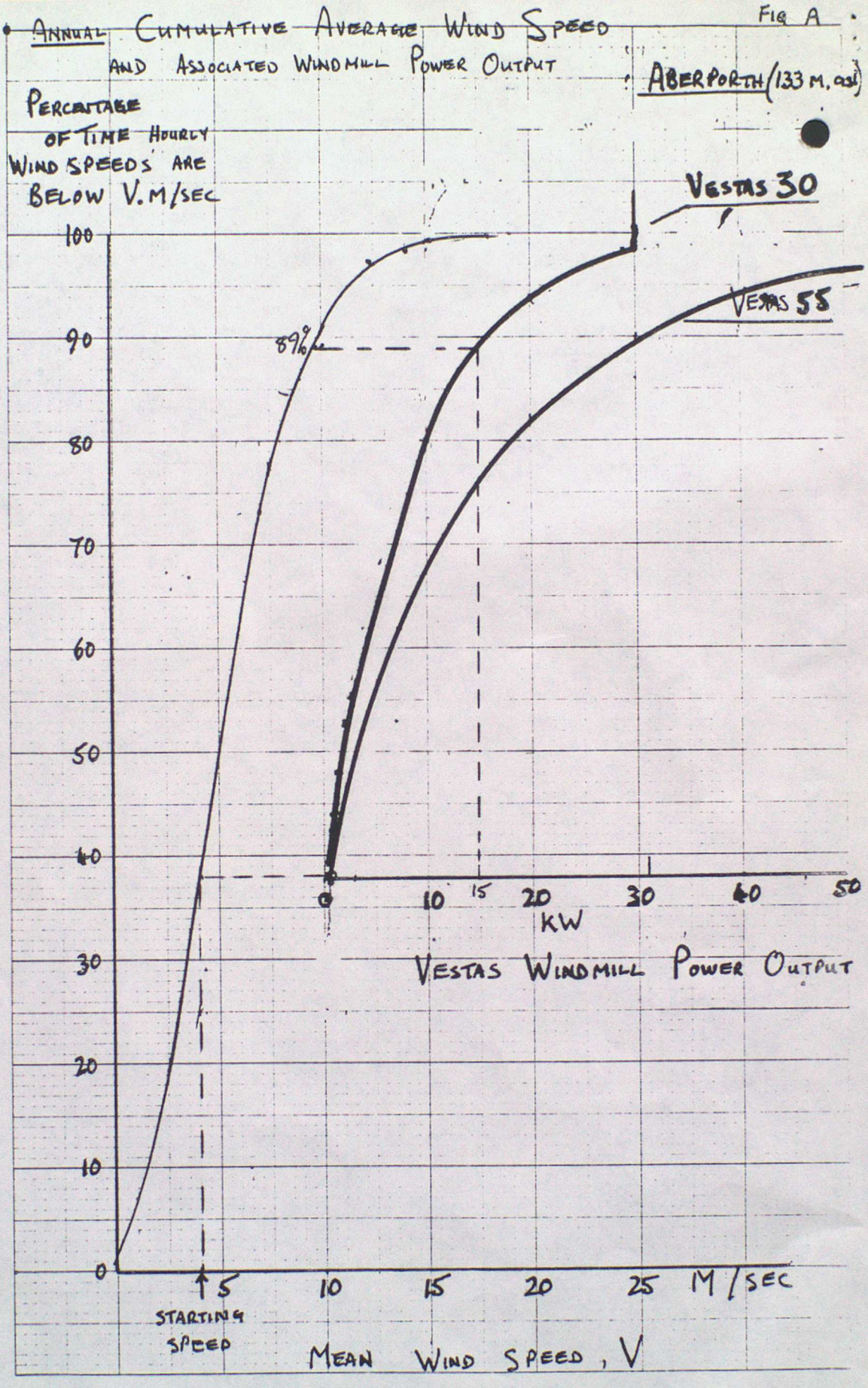
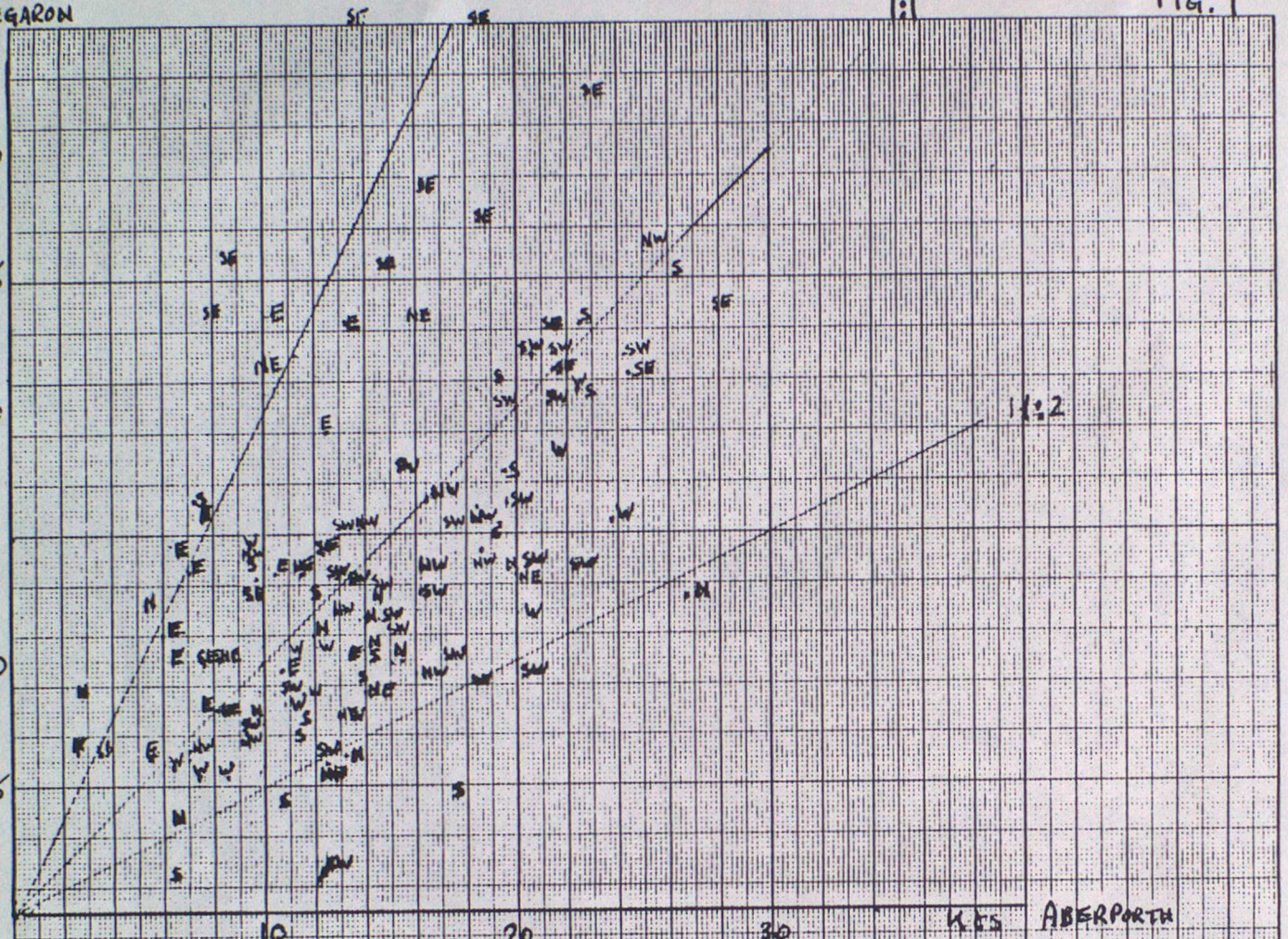


FIG. 1



1985 JANUARY - FEBRUARY - MARCH - APRIL

DAILY WIND SPEEDS (KNOTS) AT
NANT-Y-MAEN, TREGARON (500 M) - measured at 2m
AND ABERPORTH (133 M) - measured at 10 m.

FIG 1

Fig 2

Percentage of time that winds from East, West and North/South are less than V ms^{-1} at 18.5m at Nant-y-maen.

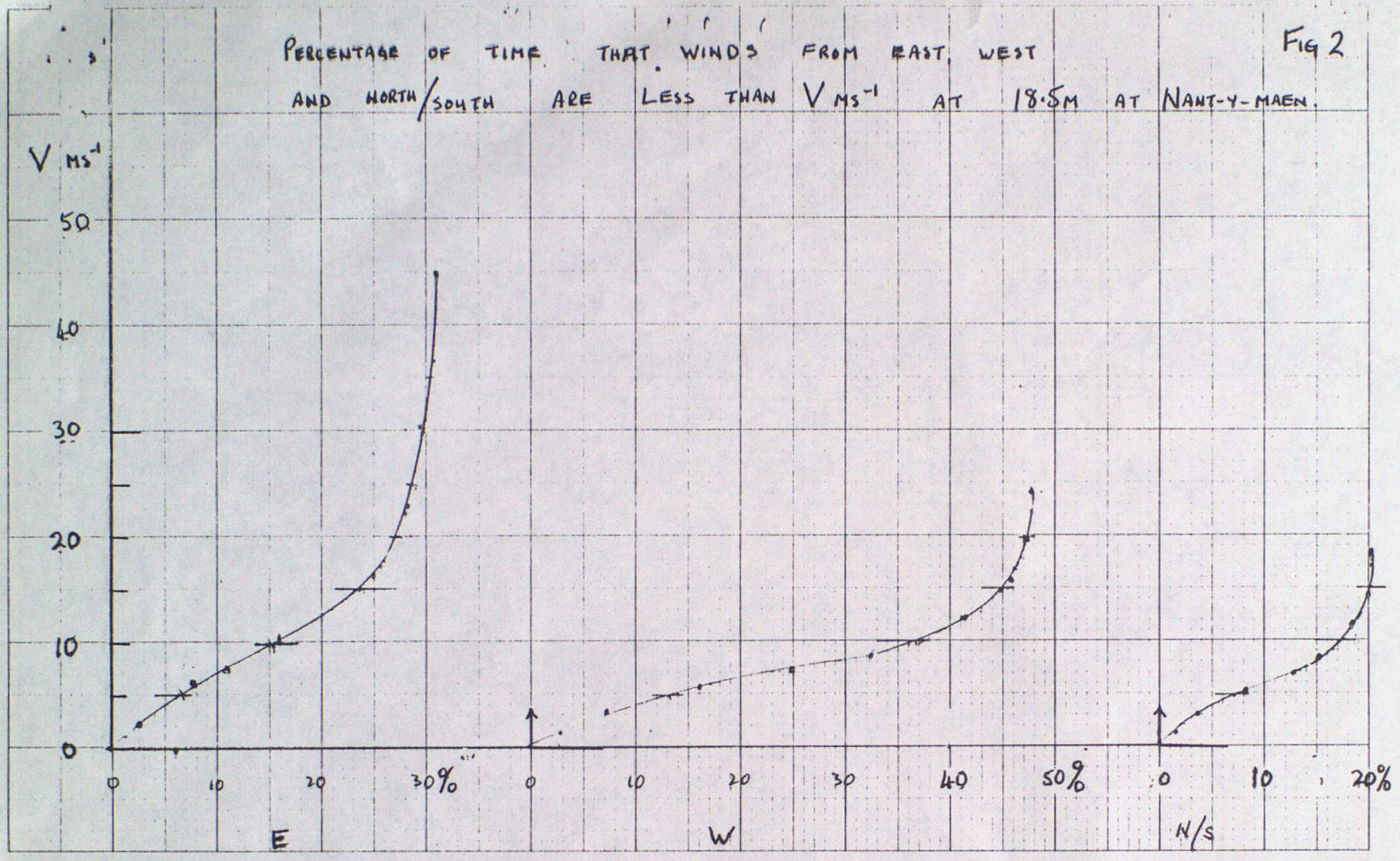
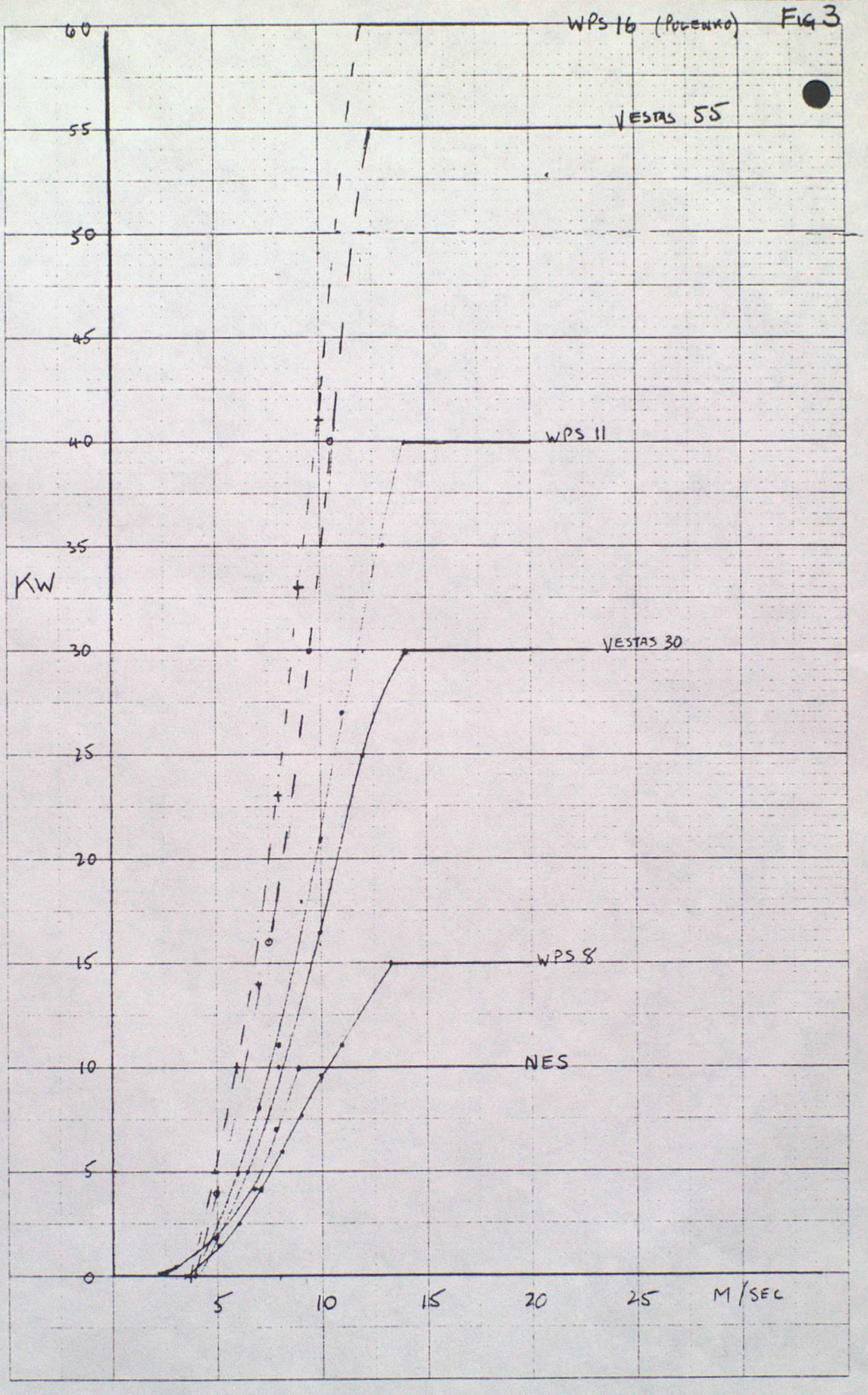


Fig 2


WPS 16 (POLENKO)
FIG 3
VESTAS 55
WPS 11
VESTAS 30
WPS 8
NES
KW
60
55
50
45
40
35
30
25
20
15
10
5
0
5
10
15
20
25
M/SEC

Ratio of Tregaron 2 m winds to Aberporth 10 m winds, R.
January-April 1985 (bracketed below: number of readings, n)

Direction	Aberporth winds (kts)						Average $\bar{R}$ (n)	Correction to 18.5 m x 1.48
	0-4.9	5-9.9	10-14.9	15-19.9	20-24.9	25-29.9		
E (020°-160°)	2.3 (1)	1.73 (12)	1.64 (11)	1.68 (4)	1.04 (5)	0.9 (1)	1.59 (34)	2.35
W (200°-340°)	- -	1.00 (8)	0.80 (16)	0.85 (13)	0.80 (11)	1.04 (1)	0.84 (49)	1.24
N 340°-020°	- -	(2)	(6)	(1)	(1)	(1)	0.72 (11)	1.15
S 160°-200°	- -	(2)	(6)	(5)	(2)	(1)	0.82 (15)	

0.78

Estimation, from Aberporth wind frequency data, of percentage of easterly, westerly and northerly/southerly winds in given speed ranges blowing at 18.5 m at Nant-y-maen

Wind range Knots	Average $V_{ms^{-1}}$	% of Easterlies	% less than or equal to V	18.5 m E wind (V x 2.35)	% of Westerlies	% less than or equal to V	18.5 m W wind (V x 1.24)	% of Northerlies and Southerlies	% less than V	18.5 m N/S winds (V x 1.15)
1–3	1.03	2.4	2.4	2.4	2.6	2.6	1.3	1.4	1.4	1.2
4–6	2.6	5.4	7.8	6.1	4.6	7.2	3.2	2.2	3.6	3.0
7–10	4.4	8.2	16.0	10.3	8.6	15.8	5.5	4.5	8.1	5.1
11–16	7	8.8	24.8	16.5	16.4	32.2	8.7	7.3	15.4	8.2
17–21	9.8	3.5	28.3	23.0	9.2	41.4	12.2	3.4	18.7	11.3
22–27	12.6	1.9	30.2	29.6	4.7	46.1	15.6	1.6	20.3	14.5
28–33	15.7	0.6	30.8	36.9	1.2	47.3	19.5	0.3	20.6	18.1
34–40	19.1	0.1	30.9	44.9	0.3	47.6	23.7	–	20.6	22.0
41–47	22.7	–	30.9	–	–	47.6	–	–	20.6	–

Table 5

Wind speed at 18.5 m at Nant-y-maen V ms^{-1}	Cumulative % less than V			Total of all directions %
	Easterlies	Westerlies	Northerlies/ Southerlies	
0–2	1	2½	1	4½
2–4	4	8	4	16
4–6	6	13	8	27
6–8	10	23	13	46
8–10	14	32½	16	62½
10–12	18	39	18	75
12–14	21	43	19	83
14–16	23½	45	20	88½
16–20	26	46½	20½	93
>20	31	48½	20½	100

Table 6

Range V_1 to V_2 ms^{-1}	% of time less than V_2	Power output P kw	
		NES	VESTAS 30
0–2	4½	0	0
2–4	16	0.5	0
4–6	27	2	2½
6–8	46	5.2	7
8–10	62½	9	13
10–12	75	10	21
12–14	83	10	28
14–16	88½	10	30
16–20	93	10	30
>20	100	10	30